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Investigations on austenitization parameters influencing wear behavior within hot stamping

Marion Merklein, Michael Wieland*

Institute of Manufacturing Technology, Egerlandstraße 13, Erlangen D-91058, Germany

Abstract

Nowadays, light weight design of the body in white is achieved by manufacturing structural components out of high strength steel grades. Due to the increase of materials tensile strength, a reduction of sheet thickness of the component is possible to attend by a weight reduction of the component with remaining or increasing components strength. Such steel grades are often processed by direct hot stamping, which can be described as forming and quenching in one process step. Due to the high temperature difference and the relative movement between the hot blank and the cold tool surfaces during the forming operation, high thermal and mechanical loads are applied on the tool. In order to avoid decarburization and scaling during austenitization, semi-finished products with an aluminum-silicon pre-coating are used. The pre-coating intensifies the occurrence of wear in terms of adhesive layer build-up on the tool. This leads to a degradation of material flow and workpiece accuracy by increasing number of drawn parts which can result in time consuming and expensive rework to remove the layer build-up and ensure components quality. Within this work, adhesive wear behavior of aluminum-silicon pre-coated boron-manganese steel is investigated under process relevant conditions. Therefore, a wear test rig is used which enables investigations on layer build-up on tools with respect to contact pressure, blank temperature and austenitization parameters following the time-temperature profile within a hot stamping operation. Adhesive wear developing on the tool contact surface is examined in dependency of the used austenitization temperature and dwell time in the furnace by means of topographic measurements of the worn tool.

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Keywords: Hot Stamping; AlSi; Wear; Austenitization

* Corresponding author. Tel.: +49-9131-85-28285; fax: +49-9131-85-27141.
E-mail address: michael.wieland@fau.de

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1. Introduction

Nowadays, light weight design of the body in white is not only achieved by a substitution of conventional steel grades by lightweight materials such as magnesium and aluminum alloys but also by manufacturing structural components out of high strength steel grades. Due to the increase of materials' tensile strength, a reduction of components' sheet thickness is possible, attended by a weight reduction with remaining or even increasing strength of the component [1]. For processing these steel, grades the direct hot stamping process can be used, which can be described as forming and quenching in one process step. Due to the high temperature difference between the hot blank and the cold tool surfaces and the relative movement between the blank and the tool surfaces during the forming operation, high thermal and mechanical loads are applied on the tool. As a result of these load cases, excessive wear can be observed on hot stamping tools. For avoidance of decarburization and scaling during austenitization, semi-finished products with an aluminum-silicon pre-coating are processed. One drawback of this pre-coating is the increased occurrence of adhesive wear by increasing number of drawn parts (Fig. 1) [2], leading to a degradation of material flow and workpiece accuracy. To remove layer build-up and to ensure the components' quality, time consuming and expensive rework is done in the press shop [3].

Within this work, adhesive wear behavior of aluminum-silicon pre-coated boron manganese steel is investigated under process relevant conditions. A new experimental setup was developed at the Institute of Manufacturing Technology with the possibility of investigating wear behavior according to the used austenitization parameters, blank temperature range during hot stamping and applied loading conditions. The adhesive layer build-up on the tool contact surface is analyzed by measuring the mean wear height.

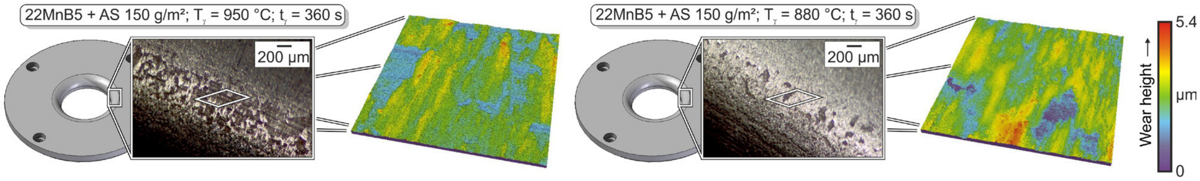

Fig. 1. Example of adhesive layer build-up on hot stamping dies after 23 drawings [2].

2. Investigated workpiece and tool material

Within this work, the steel grade 22MnB5 with an aluminum-silicon pre-coating was used for the experiments. 22MnB5 represents the common steel grade used for direct hot stamped parts in automotive industry [1]. In its initial state, the semi-finished product exhibits a fine grain ferritic-pearlitic microstructure with a good formability and a yield and tensile strength of about 400 MPa and 600 MPa, respectively. After heat treatment and subsequent quenching in the forming tool, an increase of yield and tensile strength up to 1200 and 1500 MPa can be achieved [4]. Therefore, an austenitization at a temperature above the specific Ac_3 temperature, which indicates the end austenite transformation, of about 850 °C is required to achieve the microstructural phase transformation to austenite. A fully martensitic grain structure develops by exceeding a cooling rate above 27 K/s within the quenching operation [5]. During austenitization, also the aluminum-silicon pre-coating of the semi-finished product passes several phase changes. These phase changes are related to diffusion processes of iron into the aluminum-silicon layer, increasing the melting point of the pre-coating to a temperature of up to 1100 °C [6]. Dependent on the dwell time in the furnace, different phases are developed in the aluminum-silicon coating due to the diffusion of iron into the coating. This leads to an increase of layer thickness with increasing dwell time attended by a coarsening of the coating surface. Furthermore, the development of hard intermetallic Fe-Al-Si phases support wear development on the tool surfaces resulting in grooves and adhesive layer build-up on the die radii [7]. The investigation on wear behavior was carried out using the tool steel 1.2367 which represents a standard tool steel used for warm forming tools. The tool steel was hardened to 52 + 2 HRC. The contact surface of the tool was grinded and an arithmetic mean roughness R_a of 1.059 ± 0.02 µm was measured.

3. Experimental procedure

3.1. Wear tests

For investigations on adhesive wear behavior with respect to process relevant conditions a wear test rig was developed at the Institute of Manufacturing Technology. Similar to a pin on disc test, process parameters such as contact pressure, blank temperature and also sliding velocity can be adjusted during the test cycle. This enables a systematic analysis of adhesive layer build-up in dependency of thermo-mechanical load conditions. The wear test rig mainly consists of a guided pin and a heated sheet metal support (Fig. 2). Relative sliding of the pin on the sheet metal strip is realized by a parallel kinematics robot of the type Tricept T605 (Co. PKMtricept). A pillar guide absorbs transversal forces whereby tilting of the tool is minimized and enables axial movement of the pin. The normal force on the pin is applied by a pneumatic cylinder. In addition, the pin can be heated up by a heater band enabling the adjustment of tool temperature according to multiple successive hot stamping cycles. The heated sheet metal bearing is used for adjustment of isothermal temperature conditions on the sheet metal strip and is mounted on a movable slide. An isothermal temperature in the contact area of the sheet metal strip and the tool can be realized by two ceramic flat heating elements. Wear behavior of the tool is simulated on a pin with a cylindrical shape and a flat contact surface. Table 1 lists the specifications of the test rig.

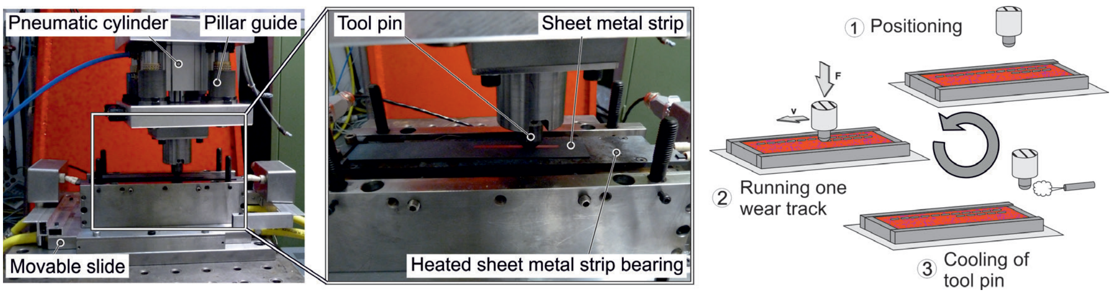

Fig. 2. Experimental setup for wear testing regarding hot stamping conditions.

Table 1. Specifications of wear test rig

Parameter	Value	Specification	Value
Max. normal force	2000 N	Max. temperature of sheet strip metal bearing	1000 °C
Normal force measurement	3 load cells à 20 kN	Max. temperature of sheet-tool contact zone	800 °C
Friction force measurement	1 load cell à 1 kN	Diameter of tool pin contact surface	4 mm
Max. tool pin temperature	550 °C		

As sheet metal strip, the steel grade 22MnB5 with an aluminum silicon pre-coating of 150 g/m² coating mass was used. The heat treatment of these blanks with a dimension of 300 mm x 29 mm x 1.5 mm is carried out in a separate furnace beside the wear test rig. For the investigation of wear behavior in dependency of austenitization parameters, heat treatment parameters were chosen as shown in Table 2. All test runs were carried out using a tool temperature T_{tool} of 150 °C, a contact pressure p_c of 10 MPa and a sliding velocity v_s of 10 mm/s. The overall sliding distance during one test run was set to 250 mm and was divided into 25 single wear tracks of 10 mm length on one blank.

Table 2. Austenitization and testing parameters.

Austenitization temperature T_γ (°C)	Austenitization time t_γ (s)	Tool temperature T_{tool} (°C)	Contact pressure p_c (*MPa*)	Sliding velocity v_s (mm/s)
930 °C	120; 180; 240; 300; 360; 420; 480; 540; 600	150	10	10
880 °C	120; 180; 240; 300; 360; 420; 480; 540; 600	150	10	10

In Fig. 3, the evolution of tool temperature T_{tool}, the blank temperature T_{blank}, the contact pressure p_c and the calculated friction coefficient μ for each wear track is shown exemplarily for the parameter combination $T_\gamma = 930$ °C and $t_\gamma = 360$ s. Tool temperature T_{tool} and blank temperature T_{blank} were measured by Ni/CrNi-thermocouples welded closely to the tool contact surface and wear track respectively. Like tool temperature in an industrial hot stamping process the temperature of the tool of the wear test rig rises during each cycle, starting from 150 °C and oscillates after 5 cycles around 165 °C. Due to the heated sheet metal strip bearing, temperature loss of the blank during each cycle can be reduced to a minimum and thus, temperature of the blank during a test run can be regarded as constant. The scattering of contact pressure p_c over all test runs averages about ± 1.5 MPa. The friction coefficient is calculated accordingly to Coulombs friction model (Eq. 1) with F_f as friction force and F_n as normal force.

$$\mu = \frac{F_f}{F_n} \; . \tag{1}$$

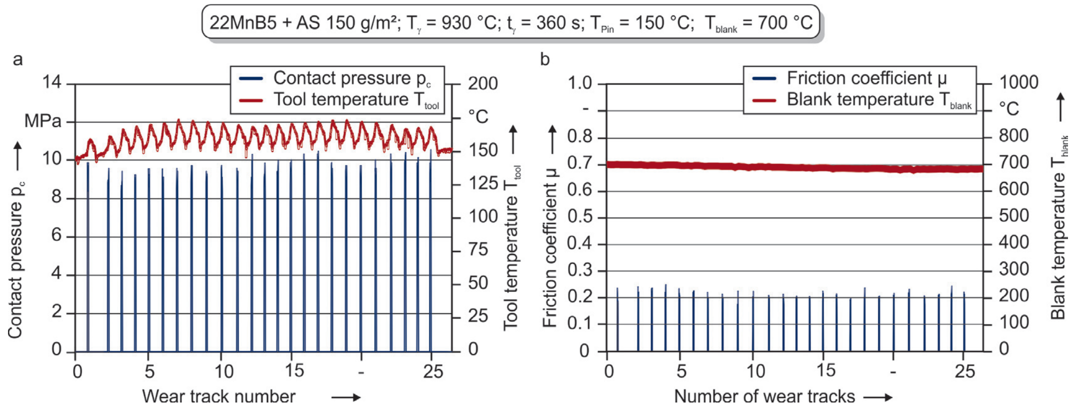

Fig. 3. Example of measured data during a test run: (a) Evolution of contact pressure p_c and tool temperature T_{tool}; (b) Evolution of calculated friction coefficient μ and blank temperature T_{blank}.

3.2. Wear height analysis

In order to evaluate the wear build up on the tool contact surface, the height of adhesive layer build-up is analyzed by means of topographical measurements. Therefore, a laser scanning microscope of the type VK-X 200 (Co. Keyence) is used. It provides the advantage of a high resolution and depth of field and combines fully focused microscope images and topographic images of the same area. For wear analysis, a representative area was chosen and was divided into 25 measurement squares of the size 50 µm x 50 µm. The distance between each square was set to 100 µm, allowing an overall measurement area of 0.4225 mm², which means a good compromise between measurement time and accuracy using a 10-time magnification lens (Fig. 4). For each measurement square, the mean wear height is determined and an overall height of the adhesive layer build-up of that area is calculated.

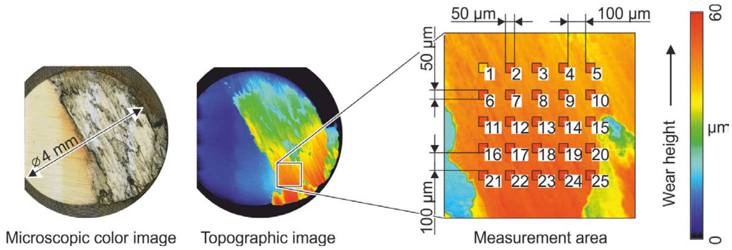

Fig. 4. Example of wear height measurement of a representative measurement area.

4. Results and discussion

4.1. Friction coefficient

The friction coefficient μ in dependency of austenitization parameters is shown in Fig. 5. By using a short austenitization time t_γ of 120 s a high standard deviation of friction coefficient μ can be seen regardlessly of the austenitization temperature T_γ. This points to unstable frictional conditions which are related to a not fully developed aluminum-silicon coating on the steel sheet. The shortest austenitization time combined with an austenitization temperature T_γ of 880 °C results in a higher friction coefficient of 0.38 in comparison to an austenitization temperature T_γ of 930 °C. For both austenitization temperatures an increase of friction coefficient μ is obvious for an austenitization time of 480 s. By increasing the austenitization time t_γ, the friction coefficient μ slightly decreases between an interval of 120 s to 360 s for the higher austenitization temperature in contrast to the slight increase at the lower austenitization temperature.

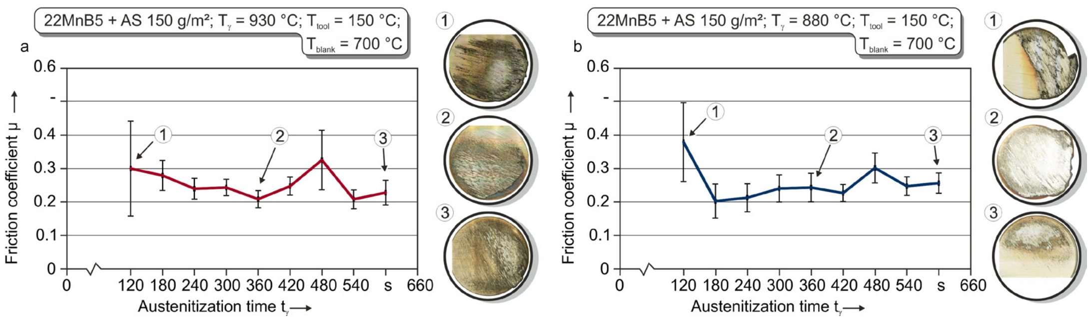

Fig. 5. Friction coefficient μ in dependency of austenitization time t_γ and temperature T_γ:(a) T_γ = 930 °C; (b) T_γ = 880 °C.

4.2. Wear behavior

In Fig. 6, the evolution of wear height is shown in dependency of austenitization parameters. The biggest wear height of nearly 40 μm can be seen for the combination of T_γ = 880 °C and t_γ = 120 s. By this short austenitization time, the iron diffusion process did not reach the top of the coating and an unchanged AlSi-coating can be found at the contact surface leading to high adhesive wear. Using a higher austenitization temperature without changing austenitization time, only half of the adhesive layer build-up develops on the tool contact surface. This is related to the time and temperature dependent diffusion of iron into the coating and the development of Al-Fe-Si phases. By increasing austenitization time, wear height decreases drastically to about 7 μm to 8 μm independent of the applied austenitization temperature. For both temperatures an increased adhesive layer build-up is obvious for the austenitization time t_γ of 480 s.

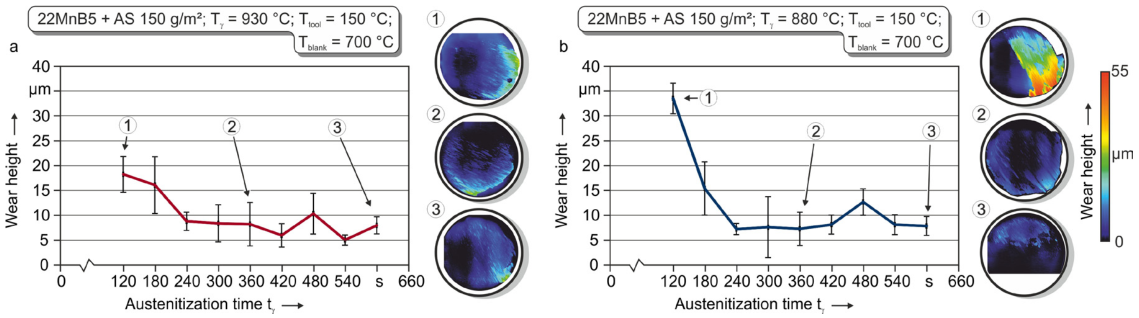

Fig. 6. Wear height in dependency of austenitization time t_γ and temperature T_γ:(a) T_γ = 930 °C; (b) T_γ = 880 °C.

5. Summary and outlook

Besides thermo-mechanical loading conditions, adhesive layer build-up on hot stamping tools also depends heavily on heat treatment parameters. As presented in this work the developed wear test rig is able to apply thermo-mechanical load conditions for wear testing with adjustable tool and blank temperatures. The results show that the development of adhesive wear of the aluminum-silicon coating on hot stamping tools increases by shortening the austenitization time. Thereby, more adhesive layer build-up develops using lower austenitization temperatures combined with short heat treatment durations due to the inadequate coating development during heat treatment. The longer the austenitization time, the less adhesive wear can be detected on hot stamping tools as a consequence of the development of intermetallic Al-Fe-Si phases in the coating. Furthermore, heat treatment parameters impact frictional conditions within hot stamping processes. Short austenitization times lead to an increased friction coefficient. When using an austenitization temperature of 930 °C a slight decrease of friction coefficient can be determined followed by an increase in the interval of 420 s to 480 s. For a low austenitization temperature a slight increase of friction coefficient can be seen by increasing austenitization time.

Further experiments will be carried out for the determination of the evolution of adhesive wear in dependency of thermo-mechanical properties within hot stamping. The influence of contact pressure as well as blank temperature on adhesive wear in dependency of austenitization parameters is a major task in future research.

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